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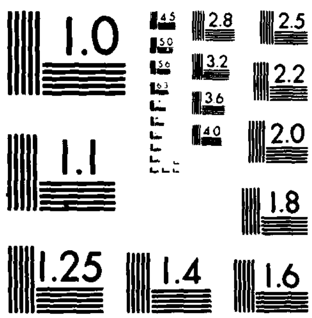

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Effects of Microstructure and Frequency on Corrosion-Fatigue Crack Growth in Ti-8Al-1Mo-1V and Ti-6Al-4V

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Mechanics of Materials Branch
Material Science and Technology Division

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Fatigue crack growth studies were conducted on Ti-8Al-1Mo-1V and Ti-6Al-4V alloys in 3.5% NaCl aqueous solution. Each alloy was studied in two microstructural conditions and at two cyclic frequencies. The Ti-8Al-1Mo-1V was heat treated to produce a fine-grained duplex anneal microstructure and a coarse-grained Widmanstätten microstructure resulting from a beta anneal. The two microstructural conditions for the Ti-6Al-4V were an as-received mill anneal and a beta anneal. The two cyclic frequencies

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20. ABSTRACT (Continued)

were 0.1 and 5.0 Hz. Each of the four alloy/microstructure combinations studied has been the subject of prior investigation regarding fatigue crack growth rate/microstructure interactions in ambient air environments. For both alloys, crack growth rates in air were found to be significantly reduced as a result of microstructural modifications associated with the beta anneal heat treatment. Although the salt water environment significantly accelerated crack growth rates for both alloys, this same ranking of fatigue crack growth resistance persisted in the present study. Both microstructures of the Ti-6Al-4V alloy exhibited a frequency crossover effect; in contrast, no significant frequency effects were observed in the Ti-8Al-1Mo-1V, in either microstructure. Similar frequency effects were seen in separate specimens cycled at a single constant frequency or in single specimens cycled at two alternating frequencies. Out-of-plane cracking was observed in both alloys in the beta annealed condition. The effects of varying degrees of out-of-plane cracking on apparent crack growth rates are noted.

CONTENTS

EFFECTS OF MICROSTRUCTURE AND FREQUENCY ON CORROSION-FATIGUE CRACK GROWTH IN Ti-8Al-1Mo-1V AND Ti-6Al-4V

INTRODUCTION

The study of high-strength titanium alloys for Naval applications has been marked by several significant discoveries during the past two decades. In the mid-1960's it was shown that some titanium alloys, previously thought to be immune to stress-corrosion cracking (SCC) in sea water, could be highly susceptible to SCC in tests utilizing precracked specimens [1]. Coincidentally, the environmental sensitivity of some titanium alloys to cyclic crack growth in salt water was also discovered [2]. In the mid-1970's, it was found that many high-strength titanium alloys were also susceptible to sustained-load cracking in relatively inert environments, possibly due to embrittlement caused by internal hydrogen [3]. Recently, it has been demonstrated that fatigue crack growth in many $\alpha+\beta$ titanium alloys can be systematically altered in a beneficial manner through microstructural modification [4].

This paper touches upon several important aspects of these prior developments. The study was undertaken primarily to investigate the role of microstructure in environmentally-assisted fatigue crack propagation of $\alpha+\beta$ titanium alloys. Recent work has shown that fatigue crack growth rates for these alloys in ambient air environments can be significantly reduced through grain-size enlargement [4]. However, the literature on corrosion-fatigue of structural alloys shows many instances where apparently superior fatigue resistance in an air environment diminishes or vanishes in the presence of an aggressively corrosive environment such as salt water. Thus, it was considered important to examine these recently discovered microstructural effects under corrosion-fatigue conditions. Other aspects relating to interactions between corrosion-fatigue crack growth and SCC, and implications relating to corrosion-fatigue mechanisms are discussed.

MATERIALS

Chemical compositions, heat treatments and mechanical properties of the materials investigated are given in Tables I-3. Microstructures are shown in Figs. 2 and 3.

Table I. Chemical Analyses (wt.%)

ALLOY	Al	Mo	V	Fe	O	N	C	H
Ti-8Al-1Mo-1V	7.8	1.0	1.1	0.07	0.11	0.015	0.03	0.0046
Ti-6Al-4V	6.7	-	4.3	0.10	0.20	0.011	0.03	0.0060

Manuscript submitted September 28, 1981.

Table 2. Heat Treatments

ALLOY	TYPE[1]	SPECIFICATION[2]
Ti-8Al-1Mo-1V	DA	(913°C/1 hr +AC) + (579°C/8 hr + AC) + (538°C/2 hr + AC)
Ti-8Al-1Mo-1V	BA	(1093°C/½ hr + AC)
Ti-6Al-4V	MA	(788°C/1 hr + AC) as received
Ti-6Al-4V	BA	(1038°C/½ hr + AC) + (732°C/2 hr + AC)

[1] DA = Duplex Anneal, BA = Beta Anneal, MA = Mill Anneal

[2] DA and BA performed in vacuum furnace. AC = cooled in helium at approximately air cooling rate.

Table 3. Mechanical Properties

ALLOY	HEAT TREAT.	0.2%[1] YIELD STRENGTH σ_{ys} (MPa)	TENSILE[1] STRENGTH σ_{uts} (MPa)	YOUNG'S[1] MODULUS E (GPa)	RED. IN[1] AREA (%)	ELONG.[1] (%)	FRAC.[2] TOUGH. K_{Ic} (MPa $\sqrt{m}$)	SCC[2] THRESHOLD K_{Iscc} (MPa $\sqrt{m}$)
Ti-8Al-1Mo-1V	DA	958	1025	136	20	13	-	24
Ti-8Al-1Mo-1V	BA	794	894	128	21	11	-	43
Ti-6Al-4V	MA	1007	1034	130	29	14	40	-
Ti-6Al-4V	BA	869	958	117	16	11	87	-

[1] T Orientation [2] TL Orientation

EXPERIMENTAL PROCEDURES

All mechanical tests were performed in general accordance with documented ASTM or Navy testing procedures [1, 5-11].

Corrosion-fatigue crack growth rate tests were conducted using 25-mm thick WOL type fracture mechanics specimens with planar dimensions conforming to the 2T configuration, as shown in Fig. 1. In all instances, crack propagation occured in the TL orientation. Specimens were cycled under constant-load-amplitude using a sinusoidal wave form and a load ratio of R = 0.1. Two cyclic frequencies were used, 0.1 and 5.0 Hz. Cyclic frequency variations were obtained by two procedures, cycling specimens to failure at separate constant frequencies or by alternating the frequency on one specimen. These two procedures will be discussed in greater detail under Results and Discussion.

The primary method of crack length measurement utilized a crack-opening-displacement (COD) technique [9]. However, visual observations of crack growth were also made, especially where out-of-plane cracking was involved. This phenomenon will also be the subject of further subsequent discussion.

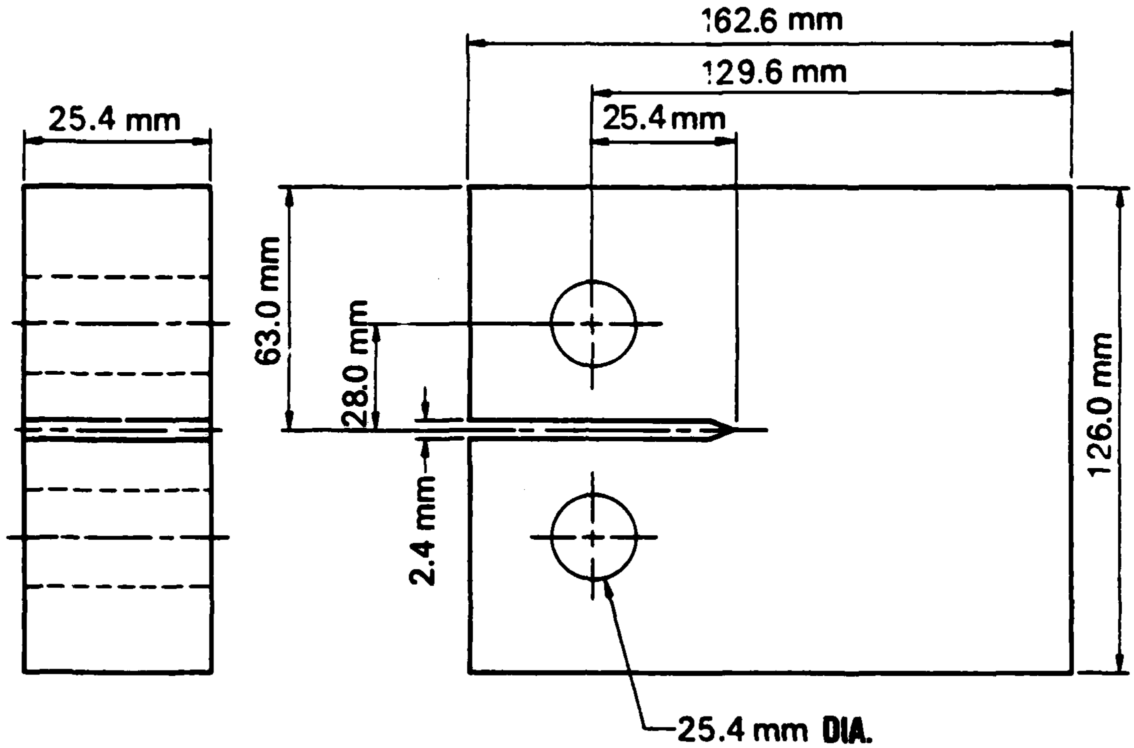


Fig. 1 — WOL specimen used for corrosion-fatigue tests. Note planar dimensions are of the 2T configuration

The corrosive environment employed was flowing 3.5% NaCl aqueous solution at room temperature. The solution was fully aerated. Specimens were freely corroding throughout the test.

Plane strain fracture toughness (K_{Ic}) values for the Ti-6Al-4V materials were obtained from tests using 25-mm thick 1T WOL specimens [12] and SCC threshold (K_{Iscc}) values for the Ti-8Al-1Mo-1V materials were obtained from tests using 22-mm thick cantilever-bend specimens [13].

RESULTS AND DISCUSSION

Throughout the presentation and discussion of the corrosion-fatigue crack growth results for Ti-8Al-1Mo-1V and Ti-6Al-4V materials studied, reference will be made to the crack growth characteristics of these materials in an ambient air environment [12, 13]. These data are shown in Figs. 2 and 3, along with microstructures for each alloy/heat treatment combination studied. All crack growth data presented in this paper will be in the format of logarithmic plots of crack growth rate (da/dN) versus stress-intensity range (ΔK).

Figs. 2 and 3 illustrate the systematic manner in which da/dN-versus-ΔK curves for $\alpha + \beta$ titanium alloys respond to changes in microstructure achieved by heat treatment. Basically the operative mechanism here is a suppression of da/dN values as a function of grain size enlargement [4]. For the Ti-6Al-4V, the mean grain size ($\bar{l}$) values for the MA and BA heat treatments are 5 μm and 24 μm, respectively. For the Ti-8Al-1Mo-1V, $\bar{l}$ values for the DA and BA are 9 μm and 60 μm, respectively. For the

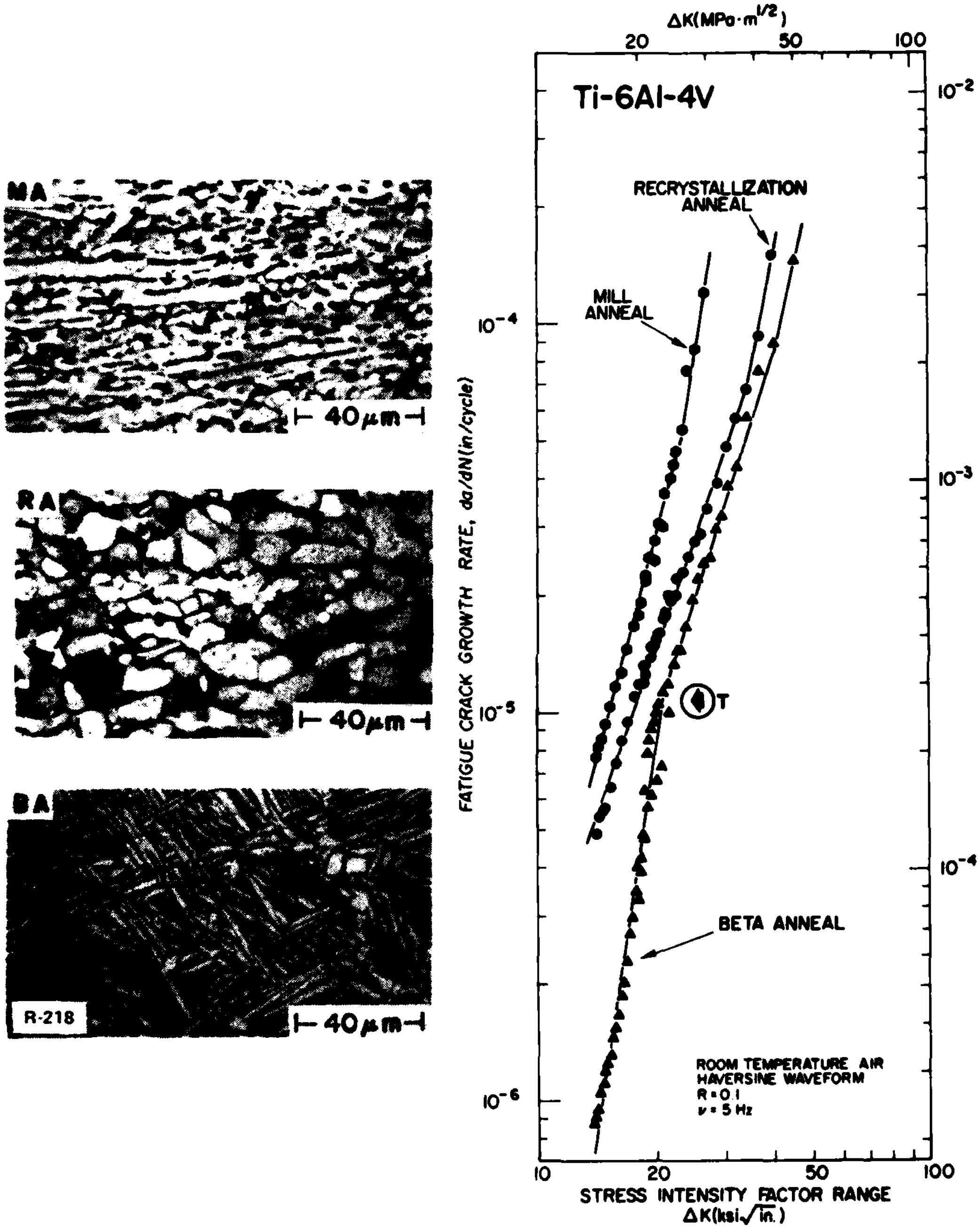


Fig. 2 — Microstructures and fatigue crack growth characteristics in an ambient air environment for the Ti-6Al-4V materials

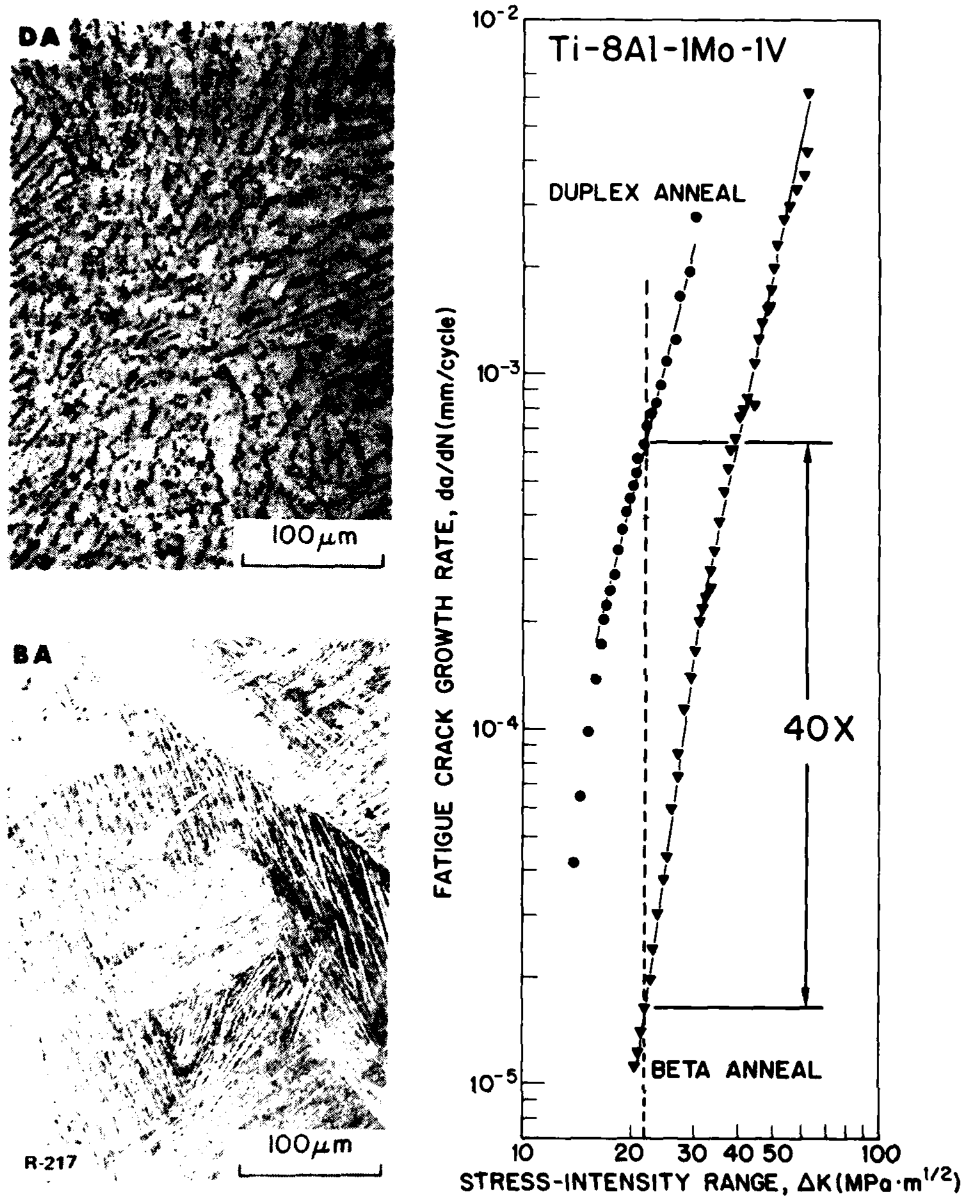


Fig. 3 — Microstructures and fatigue crack growth characteristics in an ambient air environment for the Ti-8Al-1Mo-1V materials

Widmanstätten microstructure associated with the BA, $\bar{\ell}$ is the mean packet size [4]. Thus, it was considered important to determine the degree to which a salt water environment could affect this highly favorable suppression of da/dN values achieved through the BA heat treatment.

Figs. 4 through 7 show results obtained on the Ti-6Al-4V (MA) material at 0.1 and 5.0 Hz. A noteworthy feature of these data is evidence of the frequency "crossover" effect first reported in $\alpha+\beta$ titanium alloys by Dawson and Pelloux [14] and subsequently confirmed in futher studies by Dawson [15]. The crossover effect is a reversal of the frequency-related ordering of da/dN values which is caused by a change in the dominant mode of corrosion-fatigue crack growth. The crossover occurs at a ΔK level associated with the onset of "cyclic" SCC. Dawson and Pelloux termed this ΔK level "ΔK_{scc}" and reported it to be a frequency dependent parameter which tends to be lower than the "static" K_{Iscc} value obtained from sustained load tests [1, 10]. Below ΔK_{scc}, da/dN values are controlled by repassivation of fresh metal surfaces at the crack tip. Thus below ΔK_{scc}, higher frequency, which allows less time for repassivation to occur, results in higher da/dN values. Above ΔK_{scc}, a hydrogen embrittlement mechanism becomes dominant and a reveresal of frequency effects occurs. Here, da/dN values are related to hydrogen mobility to the plastically deformed region near the crack tip. Thus, higher da/dN values become associated with slower frequencies which allow more time for hydrogen embrittlement to occur. The crossover effect is strongly evident in the da/dN-versus-ΔK data from the Ti-6Al-4V (MA) material.

For the specific conditions of this investigation, da/dN values in the Ti-6Al-4V (MA) material were not strongly affected by environment below the crossover. In this region, da/dN values in salt water are quite close to da/dN values obtained in air.

The two frequency-based curves for da/dN versus-ΔK shown in Fig. 4 were obtained by testing separate specimens at constant frequency. However, Fig. 5 shows data obtained from a single specimen cycled at two alternating frequencies of 0.1 and 5.0 Hz. That is, frequency was held constant until a sufficient Δa increment of crack growth had occurred to develop a valid da/dN-versus-ΔK data point [8, 9], then the frequency was alternated and the process repeated. Fig. 6 shows a comparison between constant frequency and alternating frequency data. The agreement appears to be satisfactory. The alternating frequency procedure was also employed successfully by Dawson and Pelloux [14]. However, this does not constitute a blanket recommendation for the procedure, especially where alloy systems other than titanium are being tested. Using a high-strength steel, Wei has demonstrated pronounced nonsteady-state transients in fatigue crack growth response in water vapor as a function of changes in cyclic frequency [16].

Fig. 7 is a schematic trend line plot of the compilation of data shown in Fig. 6. It illustrates the crossover effect and establishes the magnitude of the frequency effects seen in the Ti-6Al-4V (MA) material.

Figs. 8 and 9 show the results of a single-specimen alternating-frequency test on a sample of the Ti-6Al-4V (BA) material. Here, a similar trend in relation to the data for the Ti-6Al-4V (MA) material is apparent; a frequency crossover effect is seen and large environmental effects on da/dN occur above the crossover point. However, these data illustrate another phenomenon which occurred with both the Ti-6Al-4V (BA) and the Ti-8Al-1Mo-1V (BA) materials, namely out-of-plane cracking. As noted on Fig. 8, the crack on this specimen grew 15° out-of-plane. This is well in excess of the ±5° departure from the plane of symmetry permitted in ASTM E647-78T for valid data [8]. Undoubtedly, out-of-plane cracking is the reason da/dN values below the crossover

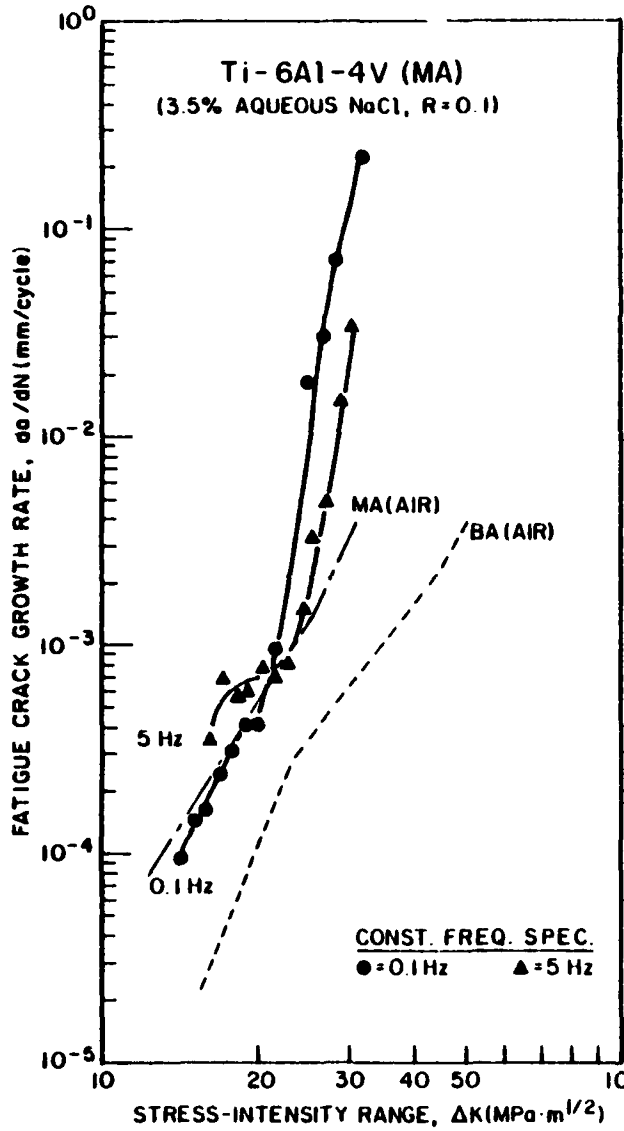


Fig. 4 — Corrosion-fatigue crack growth rate data for two separate specimens of the Ti-6Al-4V (MA) material, each cycled at a constant frequency

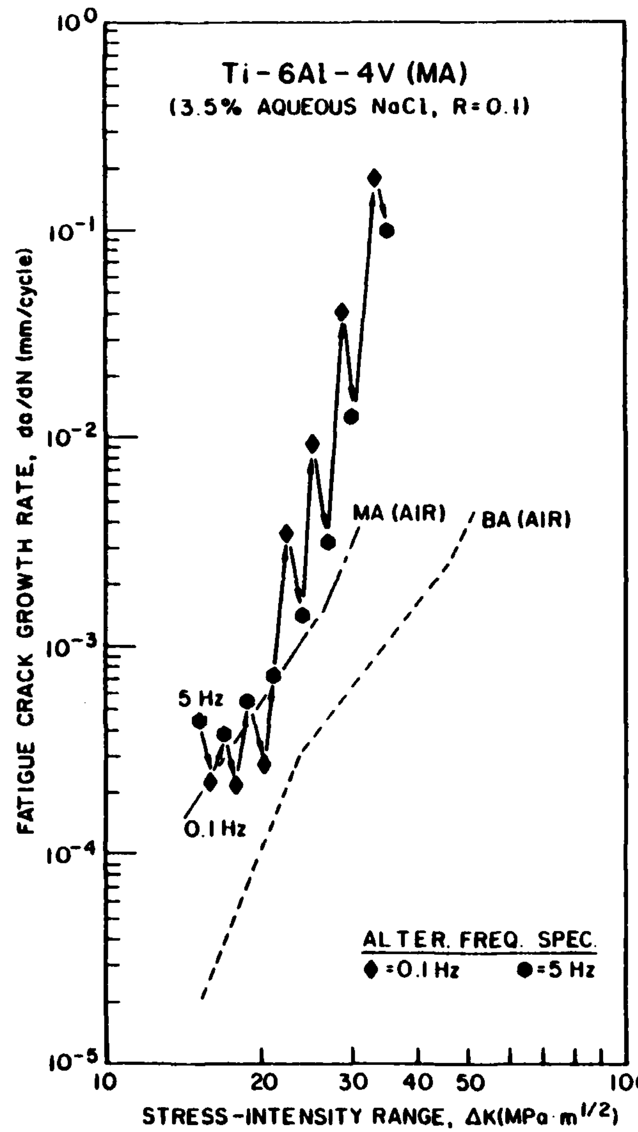


Fig. 5 — Corrosion-fatigue crack growth rate data for a single specimen of the Ti-6Al-4V (MA) material cycled at two alternating frequencies

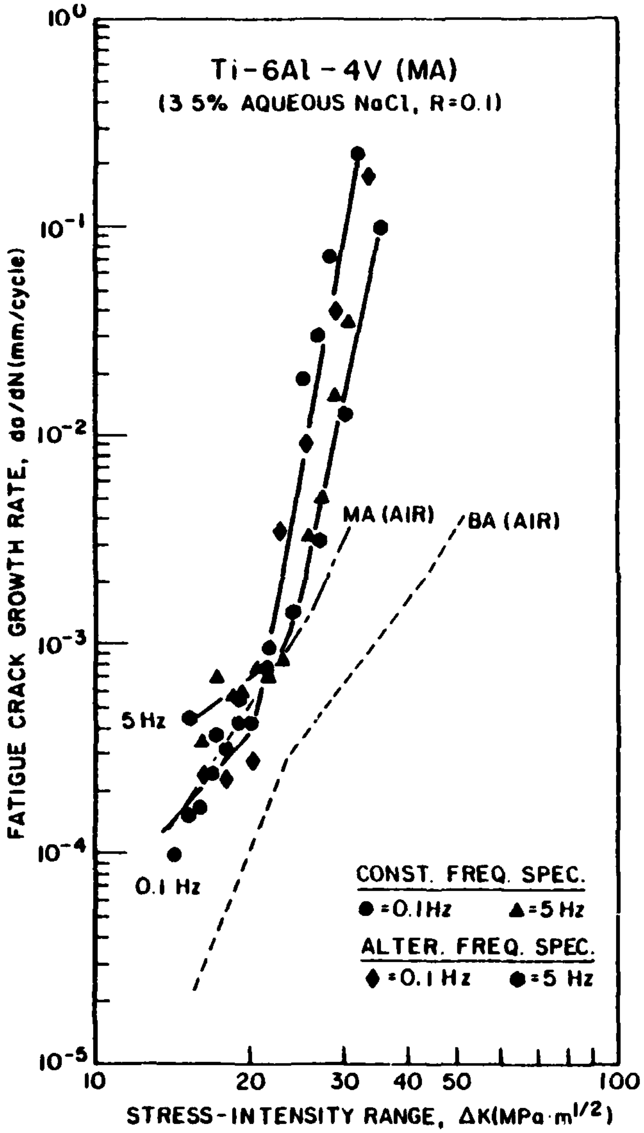


Fig. 6 — *Comparison of constant-frequency and alternating frequency data from Figs. 4 and 5*

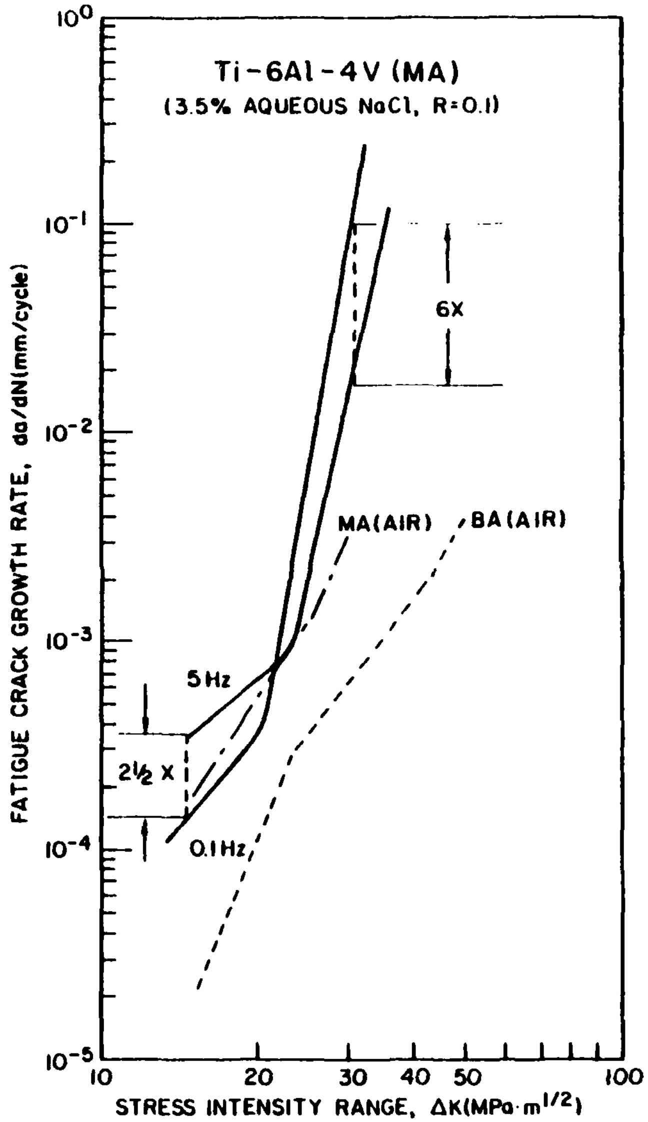


Fig. 7 — Trend lines for the Ti-6Al-4V (MA) data at 0.1 and 5.0 Hz

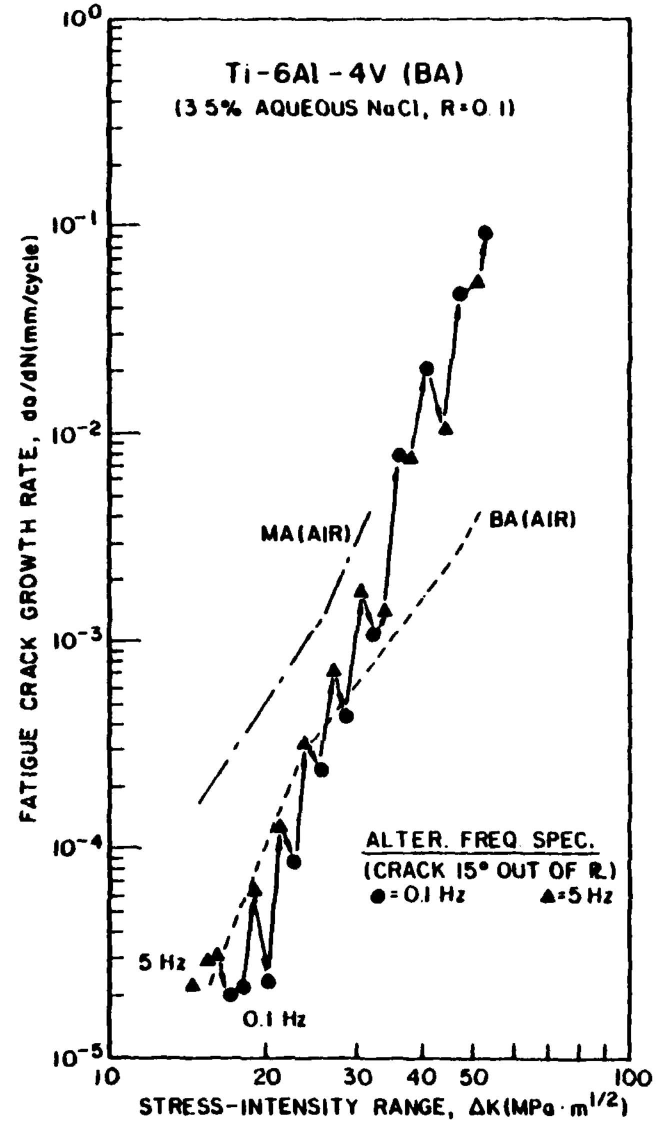


Fig. 8 — Corrosion-fatigue crack growth rate data for a single alternating-frequency specimen of the Ti-6Al-4V (BA) material. Note crack grew 15° out-of-plane.

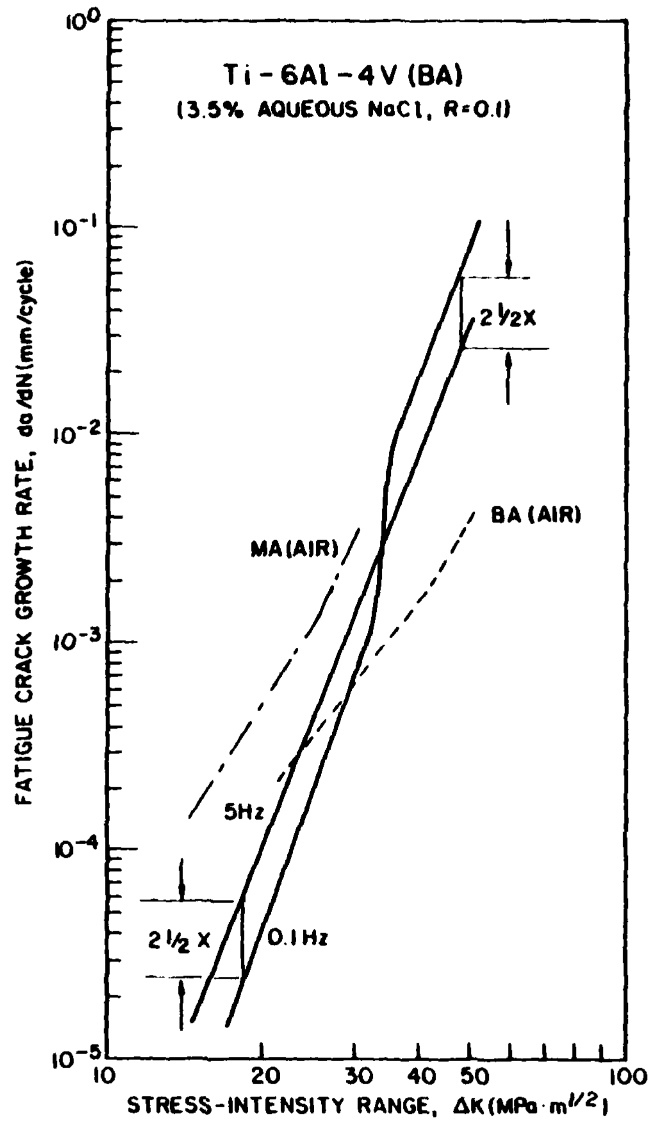


Fig. 9 — Trend lines for the Ti-6Al-4V (BA) data at 0.1 and 5.0 Hz from Fig. 8

point appear to be beneficially reduced by the presence of the salt water environment. However, despite the ambiguities in the data caused by the out-of-plane cracking, it does appear from these data that the beneficial effects of the BA heat treatment persist in the presence of a salt water environment. The BA trend lines for salt water tend to lie well below the MA trend line for air, as shown in Fig. 9.

Corrosion-fatigue da/dN-versus-ΔK data for the Ti-8Al-1Mo-1V (DA) material is shown in Fig. 10. Data for separate specimens tested at 0.1 and 5.0 Hz are plotted, and the ΔK_{scc} level is approximated by the value of 0.9 K_{Iscc} on the ΔK scale. No frequency effect is apparent in the data. This is consistent with previous observations by Meyn [17] and Döker and Munz [18] for Ti-8Al-1Mo-1V alloys. da/dN values undergo a pronounced acceleration at $\Delta K = \Delta K_{scc}$ where cyclic SCC becomes operative, which is also consistent with Meyn's extensive data on this alloy.

Figure 11 shows data from a single-specimen alternating-frequency test on the Ti-8Al-1Mo-1V (BA) material. Here, the crack grew 5^{o} out-of-plane, as noted on the figure. Frequency effects were very minor in this material, although some slight evidence of a crossover effect can be discerned. As in the case of the Ti-6Al-4V (BA) material, a beneficial effect of the BA heat treatment is apparent. Salt water da/dN values for the BA material lie well below the da/dN-versus-ΔK curve for the DA material in air. Also, the data take a pronounced upward shift at $\Delta K = \Delta K_{scc}$, where cyclic SCC becomes operative.

Since the results indicate no significant frequency effects for the Ti-8Al-1Mo-1V alloy in either of the two microstructures examined – while the opposite holds true for both microstructures of the Ti-6Al-4V alloy, it seems reasonable to suggest that the appearance of a frequency crossover effect is more dependent upon alloy chemistry than on microstructure. Thus the differences in frequency effects reported in prior studies [14, 15, 17, 18] with $\alpha+\beta$ titanium alloys can be rationalized.

Figure 12 shows additional data for the Ti-8Al-1Mo-1V material obtained from a constant-frequency test at 5.0 Hz where the crack did not deviate significantly from the plane of symmetry. These data suggest that the 5^{o} out-of-plane validity criterion expressed in ASTM E647-78T may not be entirely conservative. The spread in the 5 Hz data between the two specimens representing 0^{o} and 5^{o} out-of-plane cracks is not entirely reassuring in this regard, although this is surely not a definitive experiment on the subject.

The propensity of the BA-heat-treated materials for out-of-plane cracking raises questions regarding future fracture mechanics test procedures for characterizing their corrosion-fatigue and SCC crack growth resistance in salt water. Deviations of the crack path from the plane of symmetry by 5^{o} or more are clearly unacceptable, barring the development of new stress-intensity solutions for out-of-plane cracks in compact or WOL specimens. The remaining approach lies in the use of side-grooved specimens, which also raises questions concerning the validity of existing stress-intensity and COD calibrations.

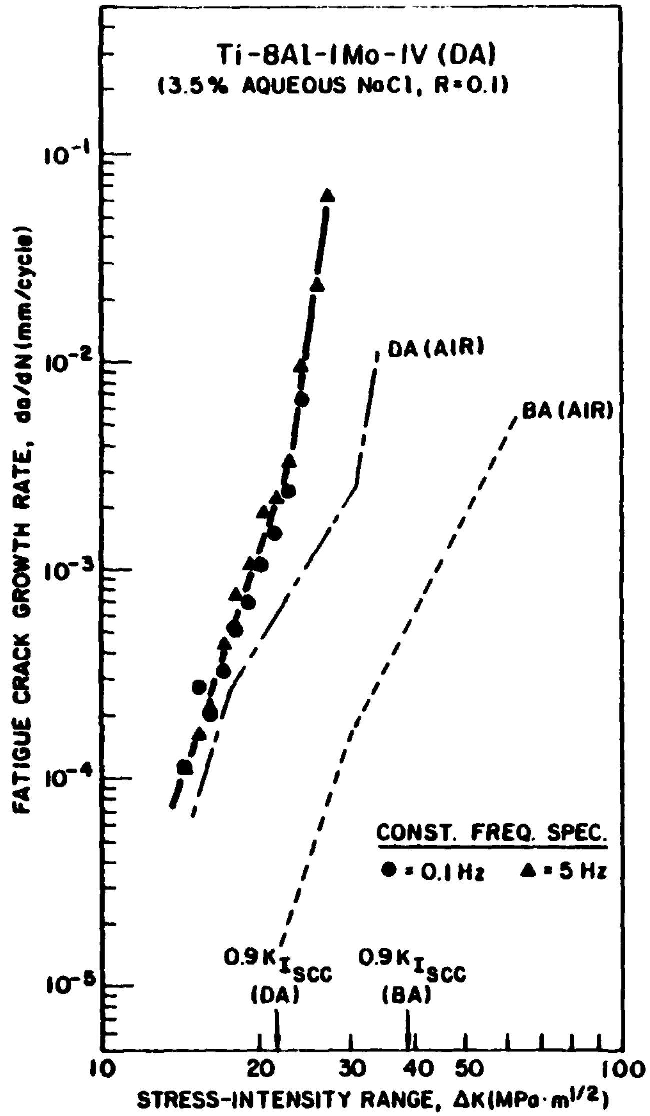


Fig. 10 — Corrosion-fatigue crack growth rate data for two separate specimens of the Ti-8Al-1Mo-1V (DA) material, each cycled at constant frequency

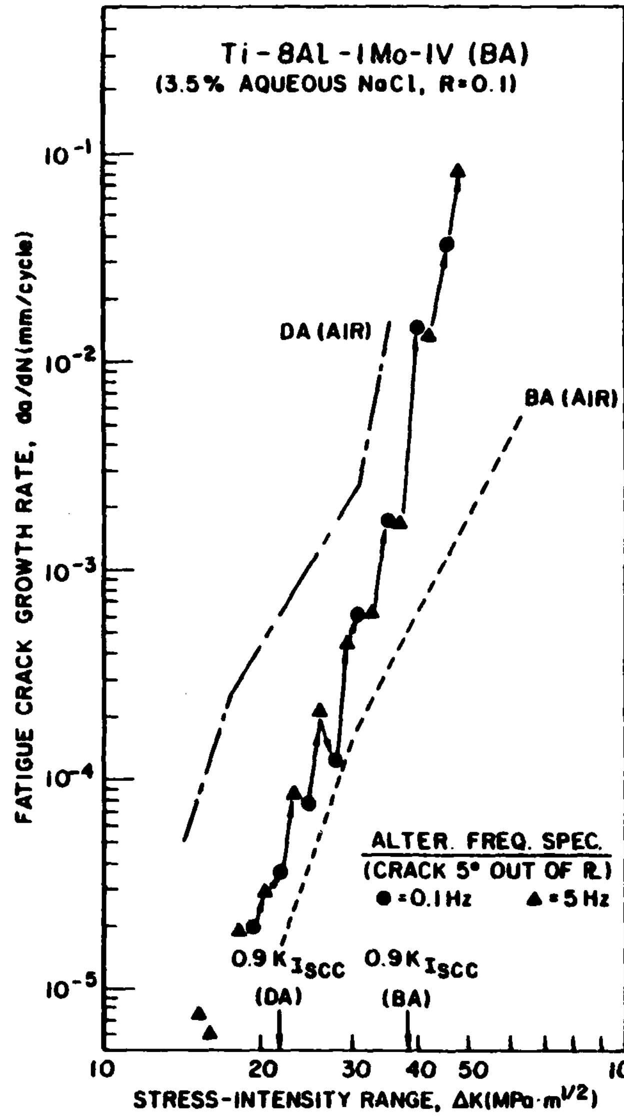
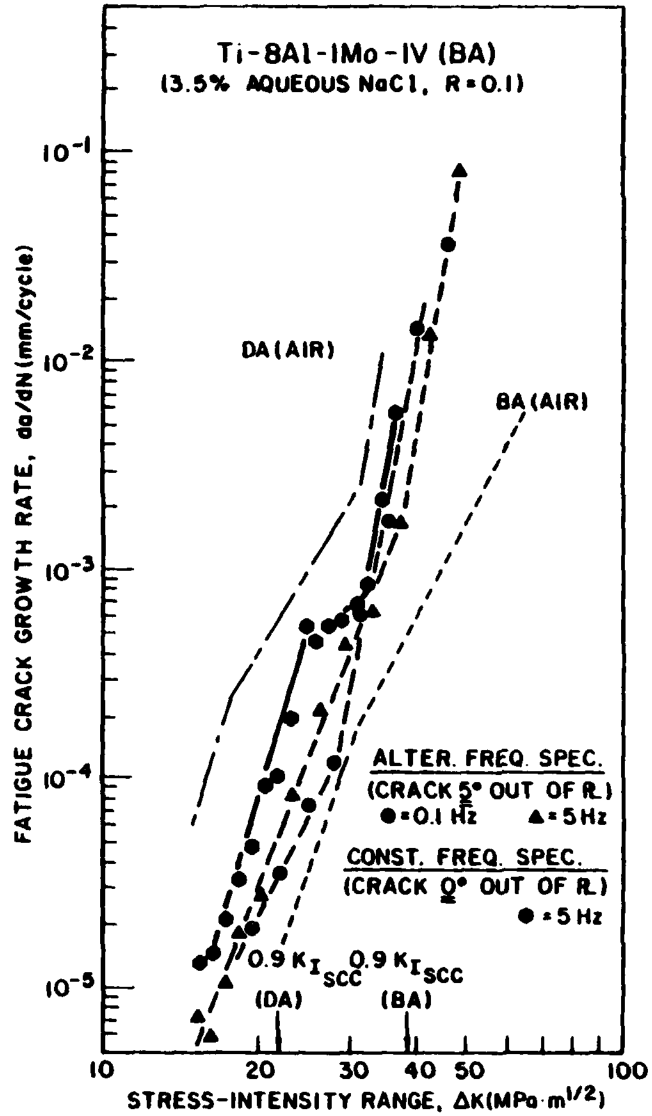


Fig. 11 — Corrosion-fatigue crack growth rate data for a single alternating-frequency specimen of the Ti-8Al-1Mo-1V (BA) material. Note crack grew 5° out-of-plane

Fig. 12 — Summation of constant-frequency and alternating-frequency data for the Ti-8Al-1Mo-1V (BA) material. Note effects of 5° out-of-plane cracking.



CONCLUSIONS

1. Perhaps the most important finding of this investigation is confirmation that the very significant degree of improvement in fatigue crack growth resistance in $\alpha+\beta$ titanium alloys associated with the BA heat treatment pertains to a salt water environment as well as to an air environment.

2. Crossover frequency effects were observed in both Ti-6Al-4V materials, which imply confirmation of proposed corrosion-fatigue mechanisms involving repassivation processes below a cyclic K_{Iscc} threshold and hydrogen-related cyclic SCC above. No significant frequency effects were observed in the Ti-8Al-1Mo-1V materials.

3. Test procedures utilizing alternating frequencies on a single specimen provided comparable results with tests conducted at constant frequencies.

4. Out-of-plane cracking, amounting to 5° or more from the plane of symmetry, proved to be a problem with both BA materials. Valid procedures for either suppressing or analyzing out-of-plane cracking in fracture mechanics tests are needed.

ACKNOWLEDGEMENTS

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REFERENCES

1. B. F. Brown, "A New Stress-Corrosion Cracking Test for High-Strength Alloys", Materials Research & Standards, Vol. 6, No. 3, March, 1966, pp. 129-133.

2. R. W. Judy, Jr., T. W. Crooker, R. E. Morey, E. A. Lange and R. J. Goode, "Low-Cycle Fatigue-Crack Propagation and Fractographic Investigation of Ti-7Al-2Cb-1Ta and Ti-6Al-4V in Air and in Aqueous Environments", Transactions of the ASM, Vol. 59, No. 2, June, 1966, pp. 195-207.

3. G. R. Yoder, C. A. Griffis and T. W. Crooker, "The Cracking of Ti-6Al-4V Alloys Under Sustained Load in Ambient Air", Transactions of the ASME, Journal of Engineering Materials and Technology, Vol. 96, Series H, No. 4, October 1974, pp. 268-274.

4. G. R. Yoder, L. A. Cooley and T. W. Crooker, "Observations on the Generality of the Grain-Size Effect on Fatigue Crack Growth in Titanium Alloys", Titanium '80 (Proceedings of the Fourth International Conference on Titanium, Kyoto, Japan, 19-22 May 1980), H. Kimura and O. Izumi (Eds.), Vol. 3, The Metallurgical Society of AIME, Warrendale, PA, 1981, pp. 1865-1874.

5. E8-79a, "Standard Methods of Tension Testing of Metallic Materials", in 1980 Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, 1980, Part 10, pp. 197-216.

6. E111-61, "Standard Test Method for Young's Modulus at Room Temperature", ibid., pp. 324-328.

7. E399-78a, "Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials", ibid., pp. 580-601.

8. E647-78T, "Tentative Test Method for Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8} m/Cycle", ibid., pp. 749-767.

9. G. R. Yoder, L. A. Cooley and T. W. Crooker, "Procedures for Precision Measurement of Fatigue-Crack-Growth-Rate Using Crack-Opening-Displacement Techniques", Fatigue Crack Growth Measurement and Data Analysis, ASTM STP 738, Edited by S. J. Hudak, Jr., and R. J. Bucci, American Society for Testing and Materials, 1981, pp. 85-100.

10. R. W. Judy, Jr., and R. J. Goode, "Standard Method of Test for Plane-Strain Stress-Corrosion-Cracking Resistance of Metallic Materials", NRL Report 7865, Naval Research Laboratory, Washington, DC, March, 1975.

11. T. W. Crooker, F. D. Bogar and G. R. Yoder, "Standard Method of Test for Constant-Load-Amplitude Fatigue Crack Growth Rates in Marine Environments", NRL Memorandum Report 4594, August 6, 1981.

12. G. R. Yoder, L. A. Cooley and T. W. Crooker, "Enhancement of Fatigue Crack Growth and Fracture Resistance in Ti-6Al-4V and Ti-6Al-6V-2Sn Through Microstructural Modification", Journal of Engineering Materials and Technology, Vol. 99, October 1977, pp. 313-318.

13. G. R. Yoder, L. A. Cooley and T. W. Crooker, "Improvement of Environmental Crack Propagation Resistance in Ti-8Al-1Mo-1V Through Microstructural Modification", in Advances in Materials Technology in the Americas - 1980, Vol. 2 - Materials Processing and Performance - MD-2, Edited by I. Le May, American Society of Mechanical Engineers, New York, 1980, pp. 135-140.

14. D. B. Dawson and R. M. Pelloux, "Corrosion Fatigue Crack Growth of Titanium Alloys in Aqueous Environments", Metallurgical Transactions, Vol. 5, March 1974, pp. 723-731.

15. D. B. Dawson, "Fatigue Crack Growth Behavior of Ti-6Al-6V-2Sn in Methanol and Methanol-Water Solutions", Metallurgical Transactions A, Vol. 12A, May 1981, pp. 791-800.

16. R. P. Wei, "On Understanding Environment-Enhanced Fatigue Crack Growth -A Fundamental Approach", Fatigue Mechanisms, ASTM STP 675, American Society for Testing and Materials, 1979, pp. 816-840.

17. D. A. Meyn, "An Analysis of Frequency and Amplitude Effects on Corrosion Fatigue Crack Propagation in Ti-8Al-1Mo-1V", Metallurgical Transactions, Vol. 2, March 1971, pp. 853-865.

18. H. Döker and D. Munz, "Influence of Environment on the Fatigue Crack Propagation of Two Titanium Alloys", Proceedings of the Conference on the Influence of Environment on Fatigue, The Institution of Mechanical Engineers, London, 1977, pp. 123-130.

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